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TENTATIVE REPORT ON THE POSSIBILITY OF UTILIZING SURPLUS  
WHITE POTATOES IN A BEET SUGAR FACTORY TO PRODUCE  
STARCH SUITABLE FOR GLUCOSE SIRUP

by

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## INTRODUCTION

The manufacture of glucose sirup from white potatoes has been suggested as a means of utilizing part of the current surplus of these potatoes. It is understood that under normal economic conditions glucose sirup could not be made in this way at a price to compete with corn sirup.

It was further suggested that beet sugar factories might be quickly modified to carry out the first stage of this operation, i.e., the preparation of a starch, which while not completely purified, would still suffice for the manufacture of a good edible glucose sirup.

The problem is to determine the suitability of beet sugar machinery for this purpose and the additional equipment that would be necessary.

This report does not give a complete answer to these questions, but embodies such conclusions as we have been able to reach in the short time available and with the limited equipment on hand.

## SUMMARY

Our work indicates the probability that, with the addition of hammer-mills, vibrating screens, and a few accessories, a beet sugar factory should be able to produce potato starch of a purity adequate for making edible glucose sirup. For instance, the Blissfield Factory of the Great Lakes Sugar Company should be able to handle 400 to 500 tons of potatoes per 24 hours with these additions. The starch recovered should be about 75% of that contained in the potatoes.

The proposed process is predicated on the use of Dorr clarifiers or thickeners to perform a settling not as complete as is customary in the production of high grade starch. We have not been able to investigate the mechanical feasibility of this operation.

The applicability of this process to potatoes received frozen has not been investigated.

The effluent waters, if they must be run into a river, introduce a serious problem of stream contamination. The B.O.D. (Biological Oxygen Demand) of the effluent waters, if untreated, would total 18,000 to 27,000 lbs. for 450 tons of potatoes. Treatment of these waters by the carbonatation process as used on beet juice would reduce the total B.O.D. by approximately 35%. Further reduction to an amount acceptable for discharge into a small river, e.g., 5,000 lbs. per day, would require some biochemical treatment such as sprinkled rock bio-filters or large ponds.

Tentative Process

The proposed process, if further investigation confirms its feasibility, would consist of the following steps:

1. Grind the potatoes in a hammer-mill with a small amount of water.
2. Add sulfur dioxide gas to the resulting slurry until the dark color disappears.
3. Mix in an amount of wash water from step No. 5 equal to the weight of the slurry.
4. Screen out the fibre from the resulting diluted slurry by means of an 80-mesh screen, washing the fibre on the screen with wash-water from step No. 5.
5. Add water to the fibre and re-screen in order to wash starch out of it.
6. Let the screened slurry settle until the pure starch comes down, removing most of the brown starch with the supernatant liquid.
7. Stir up the settled starch with water and re-settle.
8. Collect the settled starch on a filter.
9. Dry the starch if it is to be shipped.

General Discussion

This simplified process for starch manufacture is based upon two facts; first that satisfactory glucose sirup can be made from a starch appreciably less pure than that customarily marketed; second, that since the entire scheme does not depend for its success on economic considerations, it is not necessary to achieve the highest possible percentage recovery of starch from the potatoes used. The essence of the process, therefore, is simplification by the elimination of many of the steps which are customarily taken to obtain high purity and high recovery. It happens that the omitted steps are those which require machinery and equipment not found in beet sugar factories and that the simplified process requires very little machinery additional to the customary beet sugar factory machinery.

When the crude starch milk obtained by screening the fibre out of the diluted hammer-milled slurry is permitted to settle, most of the pure starch settles out in two hours. The material settling out thereafter

(the so-called "Brown starch") is a mixture of the smaller starch granules with fibre. In the conventional process this settling is allowed to proceed to completion, and various special steps are taken to separate the fibre and retain the small starch granules. In the process herein described the settling is terminated before the brown starch settles out and the latter is simply discarded with the protein water. The discarding of this fibre and finely divided material simplifies the filtrations later in the process, and improves the quality of the starch; however, it causes a loss of starch and increases somewhat the B.O.D. of the effluent waters.

The shortening of the settling time, of course, greatly increases the productive capacity of a given outfit of settlers or Dorr thickeners. It also increases the capacity of the final starch filters because the discarded material is of a character that tends to clog the filter cloth and hence reduces the daily output of a filter. An important part of the investigation, therefore, was the determination of the best compromise between high output of the factory and high recovery of starch, and between high recovery of starch and the consequent contamination of the starch by fibre. The optimum combination, when operating at 50° F., seems to be a settling time of 2 to 3 hours for the crude starch milk followed by a 1-1/2 to 2 hours resettling after dilution with water.

#### DETAILS OF EXPERIMENTAL WORK

##### 1. Grinding the Potatoes

In a typical experiment a batch of 159 lbs. of washed potatoes containing 82% moisture and 12-1/2% starch as received, was ground in a hammer-mill at the rate of 40 lbs. per minute. The mill was a No. 1 Williams equipped with three rows of hammers swinging 10" diameter; the hammers had square ends 1/16" x 1-1/2". The speed was 3550 r.p.m., giving 9300 ft. per minute tip speed. The clear space between hammers was 9" of circumference; a space much smaller would prevent the free acceptance of the potatoes by the mill. A mill screen with 1/32" holes was found to be the best; the use of 1/16" holes was found to give insufficient disintegration. 1/64" holes were also tried, but the subsequent settling operations were not satisfactory inasmuch as the white starch that settled out was contaminated by fibre.

To keep the pulp flowing through the mill screen 7 lbs. of water per minute was run through the mill along with the potatoes.

For a capacity of 450 tons of potatoes per 24 hours, a hammer-mill of size similar to Williams #30, Type NF would be required, with a 125 H.P. motor. The average load would be roughly 90 KW.

##### 2. Sulfur Dioxide

To prevent fermentation in subsequent operations, a small amount of sulfur dioxide gas was passed into the slurry until the brown color

disappeared. Potato starch factories usually use about 6 lbs. of gas per 100 tons of potatoes.

### 3. Diluting for Screening

The potato slurry was diluted with an equal weight of recycled liquor from the second screening of pulp produced in a prior run; this liquor is, of course, utilized in order to save water and reduce the amount of effluent from the process. This diluting resulted in a slurry which contained about 8-1/2 per cent solids.

It is commonly considered desirable to keep the temperature of this and all succeeding liquors at or below 50° F., otherwise slimes may form.

### 4. First Screening

To remove most of the fibre from the starch the slurry was passed over a high-speed vibrating screener equipped with a stainless steel screen 15" x 48", 80-mesh, with .0075-inch square openings. It was found that a suitable feed rate was that equivalent to 400 lbs. of potatoes per hour. Before leaving the screen the pulp was washed by spraying with 490 lbs. of the liquor from the second screening of the preceding experiment.

### 5. Second Screening

The pulp discharged over the screen was diluted with 110 lbs. of water and screened a second time, washing it on the screen with 530 lbs. of water. The "overs" from the second screening contained 11 to 14 per cent of the total starch. If these "overs" had been remilled and rescreened as is done in the conventional potato starch industry the starch loss in this operation would be perhaps halved. Alternatively, if it is desired to dry this pulp for cattle feed, for which purpose the beet pulp dryer would seem suitable, the value of this starch is not entirely lost.

### 6. First Settling

The through-liquor (starch milk) from the first screening amounted to 720 lbs. It contains, besides the starch, impurities consisting chiefly of protein with some sugars and fibre. Since we did not have available a continuous thickener of the Dorr or similar type to remove the starch from the protein water and other impurities, the separation was made batchwise in an insulated settling tank. The depth of slurry in the tank was chosen as 28 or 36 inches to approximate the conditions in a continuous Dorr clarifier or tray thickener. After the starch had settled for a definite period of time the protein water was decanted, leaving the starch together with two to four times its weight of water. This is probably somewhat less water than would be present in the underflow from a Dorr thickener. A discussion of the optimum settling time and the capacity of Dorr thickeners will be given later in this report under headings No. 8 and 6b-7b respectively.

## 7. Second Settling

Sufficient wash water was then mixed with the starch to produce the same settling depth as before. Again the starch was allowed to settle for a definite period of time and then the supernatant liquid was decanted.

### 6a-7a. Settling Rate Determinations

In the conventional potato-starch process the starch milk is let settle for 12 to 18 hours, to obtain maximum recovery. In the simplified process here being considered, the settling time is deliberately shortened so as to discard the impure fraction. The graphs of Fig. 1 show the progress of the first and the second settling operations (steps 6 and 7) as measured by the thickness of the settled-out layer of material. This dimension does not strictly indicate the weight of material settled out, because the settled layer is being slightly compacted as time proceeds; in the case of white starch, however, the discrepancy is slight, for the compacting is completed quickly.

The settling rate data at 50° F., for this graph, were determined in a glass cylinder 2-1/8 inches inside diameter and 48 inches high provided with a glass jacket four inches inside diameter. Water of the same temperature as the slurry was pumped through the jacket. The temperature of the water entering and leaving the jacket could be controlled readily within plus or minus 1° F. The slurry was poured into the inner cylinder to the required depth. At given time intervals, usually every five minutes, the height of the layer of settled starch at the bottom of the starch column was measured. As an example, starch produced by milling potatoes through a 1/32" diameter opening screen settled in the following manner from "starch milk" of 28 inches depth maintained at a temperature of 50° F. The white starch came down from the starch milk for a period of 95 minutes and settled out to a depth of 1-1/8 inches as a rather dense cake. At the end of that time the brown starch was first visible. A change in slope of the curve, beginning at 80 minutes, indicates that something other than white starch was beginning to deposit. Starting at 95 minutes and continuing until the end of the experiment, 240 minutes, the so-called "brown starch" settled out, finally accumulating a thickness of about 1/2 inch. During this period the thickness of the white starch layer beneath the brown starch increased by 1/16 inch. The brown starch is quite flocculent, not dense like the white starch. When allowed to stand for 16 to 20 hours the brown starch compacted to a small fraction of its original height and adhered to the dense white starch.

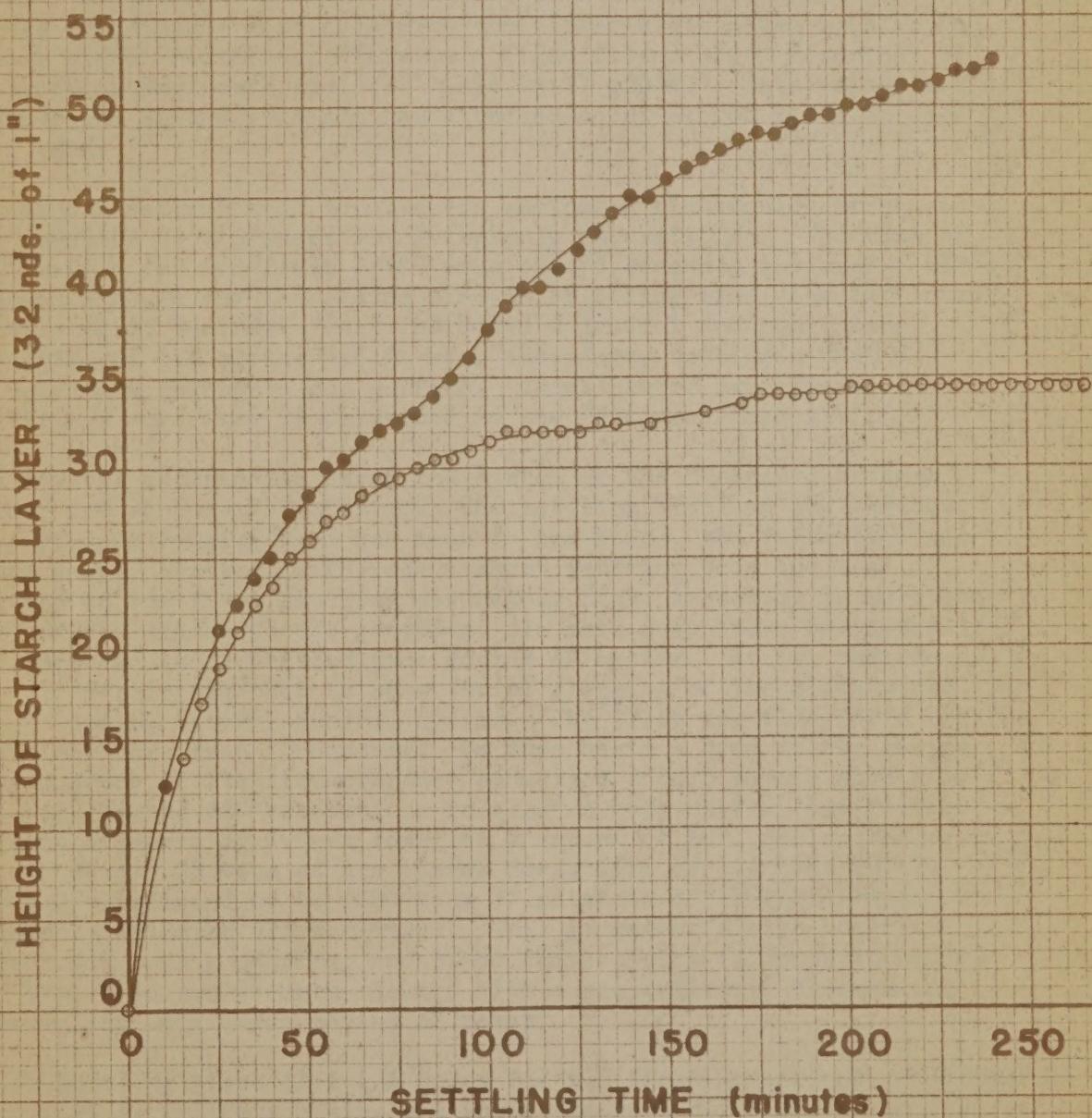
## 8. Filtration and its Relation to Settling

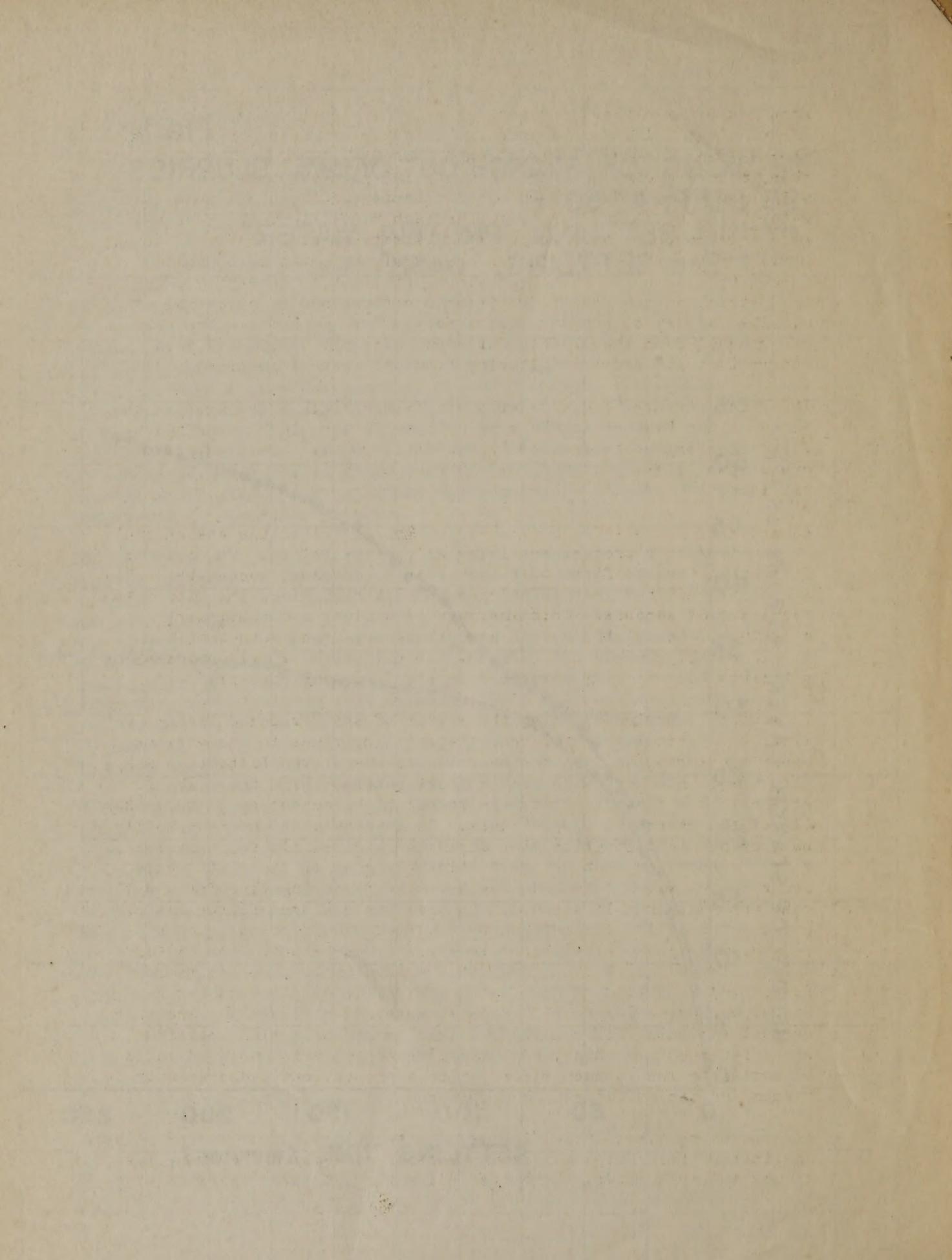
Since in the beet sugar factories the final recovery of the starch will be done by filtration on a vacuum drum filter of the Oliver type, it will be necessary to have a slurry of such character, and sufficiently free from fine particles, so that a good filtration

FIG. 1

SETTLING OF STARCH OUT OF 9% SLURRIES  
28" DEEP, AT 50°F

—●— 1st. SETTLING, "PROTEIN WATER"  
—○— 2nd. SETTLING, "WASH"





rate can be maintained for a reasonably long period between cleanings of the cloth. If, for instance, the filter drum makes one revolution in four minutes and is cleaned thoroughly every eight hours, then, allowing one hour for cleaning, 105 successive filtrations will have to be made with no other cleaning of the cloth than the water spraying which it receives at each revolution. To investigate this point we made successive filtrations of a number of equal small batches of starch slurry, previously adjusted to 5° Baume (about 9% starch), each batch being sufficient to deposit a cake 5/16" thick on the filter cloth; this corresponds to a loading of 0.9 lbs. of dry starch per square foot. Between batches the cake was removed from the cloth. For each batch the vacuum was held constant at 16" and the filtering time was accurately timed.

These experiments were made with the filter cloth often used in the Maine starch factories. This is a light filter cloth described by Filtration Engineers Inc. as "Clair Twill #5074." This weighs 3-1/4 ounces per square yard and has a thread count of 100 x 132 threads per inch.

An experiment was made to discover whether a filterable starch could be produced by a process involving only one settling. The time of filtration for the first 5/16" cake was 30 seconds; successive cakes showed a rapid and increasing rise in filtering time; the 34th cake requiring 67 seconds. This indicated a gradual and continuing clogging of the cloth; and it was, therefore, concluded that a single settling would not suffice. In all later experiments two settlements were made as described in the "Proposed Process."

In several experiments using the system of the "Proposed Process", i.e., two successive settlements, the settling times in the various experiments ranging from one hour to two hours, the filtration was very easy. However, with such a short settling time the loss of starch in the first settling was rather high, amounting to more than 11% of the starch in the potatoes. In this case there was actually no increase in filtration time during 45 cycles. It is, therefore, a fair assumption that no substantial clogging of the cloth would occur during several hundred cycles. The filtering time for a 5/16" cake was less than 15 seconds. On this basis a drum filter having one-quarter of its circumference submerged should rotate once a minute, making 420 revolutions in a seven-hour shift. One filter 8 feet diameter by 8 feet long, at a vacuum of 16", would, therefore, handle 38 tons of dry starch per shift, or 114 tons per 24 hours, corresponding to 1200 tons of potatoes of 12-1/2% starch content (assuming 75% recovery). This is rather a high rotative speed for such a machine, and since the capacity is ample it would be better to run it much slower, with a proportionate decrease in vacuum and consequent saving of power.

With settling times of 2-1/4 hours for the first and second settlements, the initial filtration time was seventeen seconds; after 40 cycles it was thirty seconds. With a settling time of three hours for the

first settling and 2 to 2-1/2 hours for the second settling, the initial filtration time was 23 seconds increasing to 32 to 38 seconds after 40 cycles.

The rate of increase became less as the test proceeded, indicating that it would not exceed 45 seconds or so. On this basis, if using 16" vacuum, the drum filter should be run at a speed of one revolution in three minutes, and each 8' x 8' filter should suffice for 400 tons per 24 hours of potatoes of 12-1/2% starch content, or 300 tons of 17% starch content. Again, if ample filters are available, a lower vacuum and slower rotation would save power.

Thus, since the Blissfield Factory has four such filters in the "first carbonatation" station, three 8' x 12' filters in the "cold saccharate" station, and two 4' x 6' in the "hot saccharate", their capacity is much more than adequate.

#### 6b-7b. Capacity of Equipment for Settling

The size and number of the settling tanks, of Dorr or other type, in any given beet factory, will be an important factor in determining the potato capacity of the factory. From the facts set forth above, it will be seen that there is no absolute settling-time that must be adhered to, but the time may be shorter or longer according to whether the settlers or the starch filters are the bottleneck. A fair compromise for the time of the first settling operation in a Dorr clarifier having three settling chambers 30" deep and one 54" deep, all operating in parallel, is perhaps two and a quarter hours. On this basis the 24 foot diameter Dorr at Blissfield having a volume of about 44,000 gallons in its settling chambers, would handle 470,000 gallons of starch milk per 24 hours. Our experiments did not include the determination of the minimum quantity of water that it would be feasible to use in the various diluting and washing operations; the amount of starch milk, i.e., the feed to the first settling tank, was closely similar to conventional potato starch manufacturing practice, viz., 1100 gallons per ton of potatoes. On this basis the 24 foot Dorr would handle 425 tons of potatoes per 24 hours.

For the second settling, as can be seen from the graph in Fig. 1, one and a half hours gives a fairly good recovery of starch at this point, and two hours is probably as long a time as is economically justifiable. For this settling we used the same dilution as for the first settling, in order to maintain for experimental purposes the same depth of liquid in our settling tank; this is somewhat more dilution than customary.

One and a half hours, using the same dilution as for the first settling, would of course require a Dorr of just two-thirds the volume as the first one. However, if the dilution is reduced enough to decrease the liquor to three-quarters as much as used for the first settling, a Dorr one-half the size of the one used for first settling would suffice. At Blissfield the small Dorr is

about 40% of the volume of the large one; it would serve this purpose at a slight sacrifice of starch recovery and a consequent increase in B.O.D. of the effluent waters.

#### Efficiency of Starch Recovery

In our experimental work the final dried starch contained about 72% of the starch in the potatoes. The loss in the pulp was usually 11 to 14%, in the "protein water" decanted from the first settling 9 to 11%, in the "wash water" decanted from the second settling 3 to 5% and the mechanical loss in the filtrate from the final starch 1/4 to 1%. The loss in the pulp could probably be halved by passing it through another hammer-mill and then over a vibrating screen. Thus in large scale operations a recovery of at least 75% of the starch in the potatoes should be easily obtainable. In an efficient potato starch factory using the conventional process; 80% recovery is usual.

#### Quality of Starch Produced

The starch produced in the final experimental run, with settling times of 2-1/4 hours in both first and second settling, was tested by the Carbohydrate Division of this Laboratory with respect to its suitability as a raw material for glucose syrup. They found that it made a syrup of good taste suitable for food uses.

The protein content of the starch produced by this process was 0.38% (calculated as 6-1/4 times the nitrogen content). This is satisfactorily close to the tolerance sometimes set for even a high quality starch of commerce, viz., 0.35%.

#### Effluents as River Contaminants

For the last two experimental starch-making runs, the effluents before and after treatment by carbonatation were analyzed for B.O.D. by the customary five-day incubation method. (The carbonatation process used will be described later in this report). The only difference between these two runs (our Nos. 11 and 12) was that in the former "protein water" settling time was 3 hours and the "wash" settling time 2-1/2 hours, whereas in the latter each time was 2-1/4 hours. The results indicated that the longer settling time reduced the total B.O.D. of the untreated effluents by about 20%, but that this difference disappeared after carbonatation.

For each run a composite sample representing the total mixture of effluents was analyzed, and also each one of the various effluents was analyzed separately so that a composite figure could be calculated as a check. In each case the latter figure was lower than the former, but the average of the figures indicates that for 450 tons of potatoes the untreated effluents will give a total of 20,000 lbs. of B.O.D. if the stated longer settling times are employed, or 25,000 lbs. if the shorter, also that the carbonated effluents will give 15,000 lbs. of B.O.D. in either case. For the system of recirculation of liquors that we used, the above three figures correspond to B.O.D. values of about 2650, 3300 and 2000 respectively for the total effluent. If a different circulation system be used, giving a different volume of

effluent, the B.O.D. concentration of the effluent will of course be altered, but the total B.O.D. in the effluent will be about the same.

These total figures check fairly well with those given in an Army report of April 4, 1945, entitled "Treatment of Potato Starch Wastes as a Means of Improving the Water at the Presque Isle Army Base". Calculations from the figures in that report show that for 450 tons of potatoes handled in that factory, using the conventional process for producing starch, the protein water would give 20,000 lbs. of B.O.D., the wash waters 1000 lbs., the "Brown starch" 1000 lbs., and the pomace (pulp) 8700 lbs. The report quotes the results of attempts to reduce the B.O.D. by various methods, chemical and other. For treating the protein water chemically, various combinations and quantities of ferric sulfate, ferrous sulfate, alum, sulfuric acid, caustic soda and lime were tried. Of these the best was lime; the results improved as the quantity of lime was increased, but only a 25% reduction in B.O.D. was obtained with 2% of  $\text{Ca}(\text{OH})_2$ , which was the greatest quantity tried. Heating the protein water to  $160^{\circ}$  F. gave a heavy floc; filtering this through a few inches of sand gave a clear effluent, but the reduction in B.O.D. was still only 25%. "High-rate bio-filtration" was the only treatment that gave really good results; this reduced the B.O.D. by 72%, i.e., to an equivalent of 5600 lbs. for 450 tons of potatoes. This was a rock filter six feet deep, using pre-ripened stone and operated at a loading stated to be "15,500 lbs. per acre ft. per day or about 3-5 times the recommended loading for this type of filter".

#### Details of Carbonatation Process

The conditions used here were similar to those used in the "carbonatation", or "carbonation", step customarily employed in clarifying the "thin juice" in beet sugar factories. This step is in some factories done batchwise, in others by a continuous recirculation of the juice with a small addition of lime and later of carbon dioxide each time the juice is recirculated. This work was carried out by the Carbohydrate Division of this Laboratory, using the batch process. The protein water or other effluent to be treated was heated to  $185^{\circ}$  F. then freshly slaked powdered lime was added in an amount equal to 0.50% of  $\text{CaO}$ , equivalent to 0.66% of  $\text{Ca}(\text{OH})_2$ , based on the weight of the water. This is of course far more than can be dissolved in the water; the excess remains in suspension.

Carbon dioxide gas was then passed into the liquid, which was kept in strong agitation by a motor-driven stirrer, until the pH fell to 10.0 plus or minus 0.3, the temperature being maintained at  $185^{\circ}$  F. The liquid was then let stand overnight to settle, cooling to room temperature and a sample of the clear liquid siphoned off for B.O.D. analysis. The time of operation was roughly 40 minutes for heating, 5 minutes for adding the lime and 30 minutes for gassing.

A similar set of experiments using one-half the above quantity of lime gave about nine-tenths as great a percentage reduction in B.O.D. Preliminary trials, made with 0.6%, 1.1% and 1.8%  $\text{CaO}$ , all gave effluents of the same clarity as judged visually.